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The Science, the Law and the Economics of Industrial Health

CONTENTS

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Ventilation of Plating Tanks

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SINCE 1928, when Bloomfield and Blum[1] made a study of the health hazards of chromium plating, considerable attention has been focused upon the ventilation of plating tanks of all kinds. While the recommendations for control of the health hazard by means of transverse or lateral exhaust ventilation given by Bloomfield and Blum are valid even today several attempts have been made since then to define more specifically the required ventilation rate.

Riley and Goldman,[2] in 1937, undertook a short study of plating tanks and presented a simple equation for the computation of the required amount of ventilation. (See Table 1.) The equation they suggested provides essentially the same ventilation rate as recommended by Bloomfield and Blum. This equation with but minor modifications is in wide use today and is incorporated in the Appendix of the proposed American Standard Safety Code for Exhaust Systems in Electroplating Operations. More recently Battista, Hatch and Greenburg[3] reported the results of a study on the ventilation characteristics of a plating tank provided with lateral exhaust ventilation. Their results indicate that the quantity of air which must be exhausted for a given velocity over the remote part of the tank is a function of the tank width to the 0.6 power. (See Table 1.) (NOTE: the value of 1.6 given in their paper is in error,— it should be the reciprocal of 1.6 or about 0.6.) Silverman,[4] in a paper about to be published, shows that for a given velocity over the remote corners of a tank, Q (quantity of ventilation per unit time) is a function of the tank length to the 0.85 power and the tank width to the 1.15 power. (See Table 1.)

Before the results of the studies of Battista, Hatch, Greenburg and Silverman became known

to us, the differences in opinion voiced by those people who submitted comments on the proposed electroplating code made it apparent that no uniformity of opinion on the proper ventilation rate or the determination thereof existed among those interested. Consequently, a study was undertaken to determine (1) the air flow characteristics of plating tanks provided with lateral exhaust ventilation, and (2) the minimum velocity at the remote point or area over the plating tank necessary to maintain the concentration of chromic acid mist in the air of the workroom and in close proximity to the tank below the permissible safe limit of one milligram per 10 cubic meters of air. Only the first part of this study has been completed, and it is to a discussion of the results of this study that the remainder of this paper will be devoted.

Method of Test

A TANK six feet long by two feet wide and with a flat surface about seven inches below the bottom of the exhaust slot opening was constructed essentially of masonite. Exhaust hoods having inside dimensions of 6 in. x 10 in. x 6 ft. long were made, of $7/8$ in. board. These hoods were provided with an adjustable lip or flange of sheet metal so that the slot width could be adjusted from 0 to 3 inches. The lip or flange forming the lower part of the slot extended into the hood proper a distance of $2\frac{1}{2}$ in. simulating to a certain extent the upper edge of a typical plating tank. (See section in Fig. 2.)

Each hood was connected to a 12 in. square exhaust manifold by means of three pipes of 6 in. diameter. The purpose of this layout was to obtain a fair degree of uniformity of slot velocity throughout the entire hood length. The exhaust hoods served as the sides of the tank and in that part of the study devoted to the characteristics of a single hood the unventilated hood was lowered so that its top was at the same level as the lower edge of the exhaust slot.

The velocity determinations were made in a plane normal to the slot and half-way between the ends of the tank. The thermo anemometer was used for the determination of the velocities and several results in the high velocity range were checked with a point velocity type Pitot tube.[5] The quantity of air exhausted was measured by orifice meters in the exhaust ducts.

It was intended that a ventilation rate of 120 cfm. per square foot of tank area, as set forth in the proposed American Standards Safety Code for Exhaust Systems in Electroplating Operations, would be used. However, the exhauster available for the study moved only 1320 cfm. or 110 cfm. per square foot of tank area. For a slot width of exactly one inch the slot velocity at this rate of flow would be 2640 fpm. However, with our slot arrangement the width could not be regulated with any great degree of accuracy and happened to be somewhat greater than one inch, resulting in a slot velocity of about 2200 fpm.

Ventilation Characteristics

A SIMPLE mathematical analysis of the problem will demonstrate that for a line source of exhaust of infinite length, V must vary inversely as the first power of X—the distance from the line source—since the successive velocity contour surfaces will be concentric cylindrical surfaces with the line source of exhaust as the axis. Carrying this analysis a step farther, it is obvious that for all practical purposes the same relationship exists in the plane normal to a line source of suction at its midpoint if the source of suction is merely long enough to produce flat velocity contours in a plane through the axis of the line source of suction. Therefore, it seems likely that this relationship, namely, that V varies inversely as the first power of X, would not be modified significantly in the case of a one-inch slot six feet long so long as no surfaces exist nearby to alter the contour pattern. In other words, the relation between rate of ventilation and tank width is Q=KLVX in which

> Q=air volume per unit time,
> K=a constant,
> L=slot length,
> V=velocity at distance X from slot,
> X=distance from slot at which V is determined.

However, in the case of a plating tank six feet long and two feet wide with a flat surface seven inches below the center line plane of the slot the contour pattern will be distorted, that is, due to the restricted areas from which no air can be exhausted the velocity contours in the plane normal to the slot at its midpoint will be expected to be extended or become separated adjacent to the zones of restriction. If this assumption is correct, it follows that V will vary inversely as X to some exponent less than one and that this exponent will not be constant unless the influence exerted by the restriction is uniform from slot outward X distance which is not the case with a plating tank. That is, if we substitute tank width W for distance from slot X in the equation given above, it becomes Q=KLVW^a in which the value of "a" is less than one and is not constant for different tanks.

Results of Study with One Hood

SINCE Dalla Valle's[5] general equation $\frac{V}{V_o-V} = KX^{-a}$ gives the relation between the center

TABLE 1.

EQUATIONS IN USE OR SUGGESTED FOR THE DETERMINATION OF THE VENTILATION RATE FOR PLATING TANKS

Equation	Source	Remarks
Slot velocity of 2000 fpm and increasing slot width as tank width increases	Bloomfield and Blum	Adequate control but not defined by equation
Q=100LW	Riley and Goldman	Ventilation rate possibly slightly low for adequate control
Q=120 LW	American Standards Association. (Outgrowth of equation by Riley & Goldman)	Found to be adequate generally and in very wide use
Q=KLW$^{0.6}$	Battista, Hatch and Greenburg	Value of "K" not yet determined
Q=2.3L$\rho^{.85}$W$^{1.15}$V	Silverman	Not yet published

line velocity V at various distances X from the exhaust opening and the velocity Vo through the opening, the values of the function $\frac{V}{V_o-V}$ were plotted on double logarithmic paper against the corresponding values of X so that the value of the exponent "a" might be determined.

In Fig. 1 is shown the relation of the center line values for the function $\frac{V}{V_o-V}$ to the corresponding values of X in inches. The resulting curve bears out the previous analysis. Since this relationship is not a straight line, it is impossible to define it by means of any simple equation. However, from the point of view of controlling the gas and/or mist hazard in plating operations, the criterion seems to be a minimum air velocity toward the exhaust slot at the remote edge of the tank. Obviously, if the air velocity at the remote edge of the tank is adequate to carry the gas or mist into the exhaust system, at any point nearer the slot, the velocity will be more than adequate. Therefore, it may be desirable to estimate the value of the exponent "a" in the zone of minimum control velocity, that is, near the side of the tank opposite the hood. From the slope of the broken line at the lower end of the curve, this value is found to be about 0.50. Consequently the equation $Q=KLVW^{0.5}$ defines the relationship between the quantity of air to be exhausted and the center line velocity which will exist at the remote edge of the tank. While the minimum controlling velocity at the center line point most remote from the exhaust hood has not yet been determined, there is reason to feel that this value will be in the neighborhood of 75 fpm. If this value is correct, the equation for the calculation of the amount of ventilation necessary for tanks of about 12 to 30 inches in width and supplied with only one exhaust hood is $Q=175\ LW^{0.5}$.

It must be recognized, of course, that this equation may not be accurate for tanks of any width except 24 inches since the curve of Fig. 1 might not be the same for tanks of other widths inasmuch as any change in the location of the wall opposite the exhaust slot alters the velocity contours and the resultant curve to some extent. However, since tanks of greater width are usually provided with two exhaust hoods and for narrower tanks the error is on the safe side, it is felt that this equation will apply generally for tanks with one exhaust hood.

Since the equation $Q=120LW$ has been used extensively and with good results as regards control of the contaminant, it may be well to see how the two equations compare. By the above equation for a tank 6 ft. long by 2 ft. wide $Q=1440$ cfm. From equation $Q=175\ LW^{0.5}$ Q for a similar tank $=1488$ cfm. This same agreement does not exist, however, for tanks of all widths. For tanks less than 24 inches wide, the ventilation rate per unit width required by the new equation increases and for tanks over 24 inches it decreases whereas with the equation now in use, it remains constant.

In Fig. 2 the velocity contours in a plane normal to the exhaust slot at its midpoint are shown. These contours demonstrate the distortion pro-

duced by the tank wall opposite the exhaust hood. This distortion improves the ventilation characteristics, since for a given Q the remote velocity contours extend beyond their normal path toward the critical velocity zone. In other words, if it were not for the wall on the unventilated side of the tank the 70 fpm. contour would cross the center line about 14 inches from the slot instead of 23 inches from the slot and at 24 inches out or at the critical point the velocity would be only about 41 fpm.

As indicated in the introductory analysis, it is the tank wall on the unventilated side and to some extent the flat surface seven inches below the slot which cause the exponent of X or W to be less than one and the relationship between $\frac{V}{V_o-V}$ and X to be a curve rather than a straight line. This may be substantiated if the velocities as taken from the contours vertically above the slot in Fig. 2 are used in the function $\frac{V}{V_o-V}$ and this function plotted against the corresponding distances above the slot. As shown in Fig. 3 a straight line having a negative slope of 1 will result.

Effect of Slot Width

WHILE it has been shown by Dalla Valle[5] that slot or face velocity per se has little influence at even short distances from the hood, this fact is not generally recognized. The important factor is the quantity of air exhausted as is illustrated by the table in Fig. 4. This table gives the center line velocities at different distances from the midpoint of a one-inch and two-inch slot with Q remaining the same in both cases. These results indicate that the influence of the higher velocity is lost at a distance of two inches from the face of the

Relation between center line velocity and distance from slot — (One slot type hood with one inch slot)

Relation of X and $\frac{V}{V_o-V}$ wherein

X = Distance out from slot along normal at midpoint
V = Velocity at distance out-x
K = Velocity at slot

X — Distance Out

Fig. 1.

Fig. 2.

RELATION BETWEEN VELOCITY IN FREE ZONE AND DISTANCE FROM SLOT.
(ONE SLOT TYPE HOOD WITH ONE INCH SLOT.)

Relation of X and $\frac{V}{V_0-V}$ wherein

X = distance vertically above slot at midpoint,

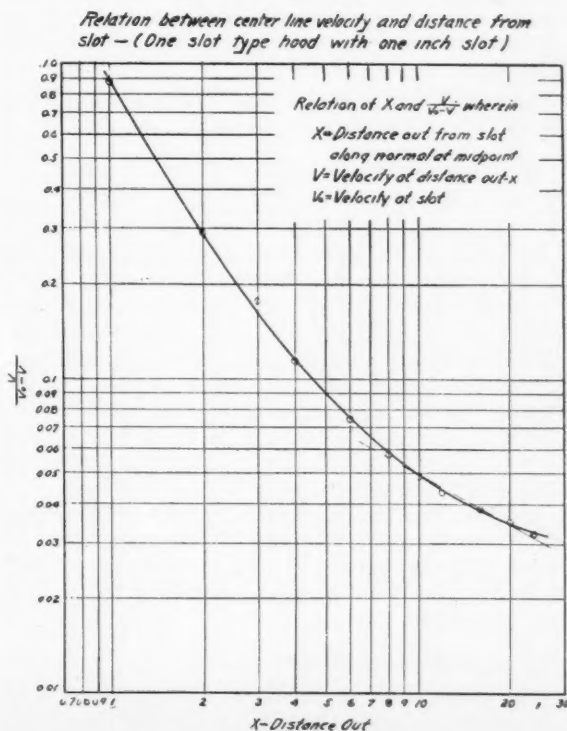V = velocity at distance X
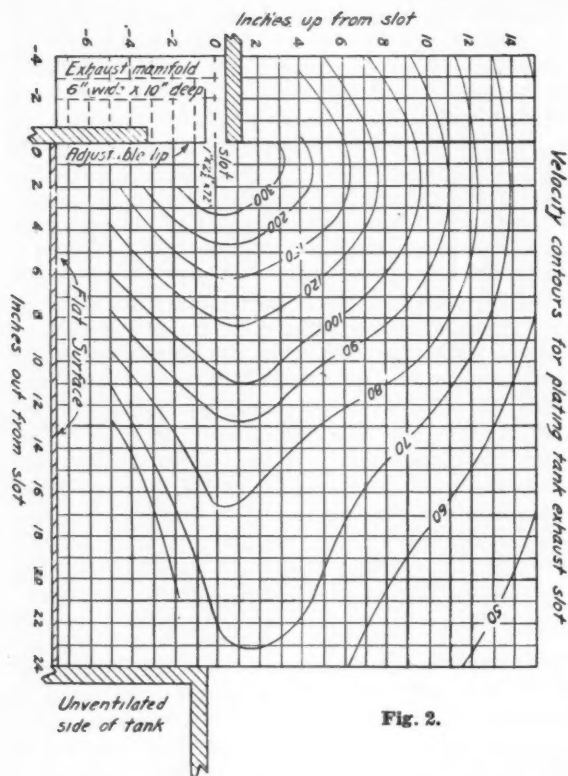
V_0 = velocity at slot

X = Distance up

Fig. 3.

slot. Obviously this distance will increase slightly as the difference between the slot widths increases. The apparent discrepancy between the slot velocities, as pointed out previously, is due to the fact that the adjustment of the slot widths is not very accurate so that they may vary substantially from the values given. However, this is of little consequence since the slot velocities were measured in all cases.

The curves of Fig. 4 are similar and essentially parallel as is to be expected.

Ventilation Characteristics with Two Hoods

FROM the equation $Q=KVLW^{0.5}$ it might seem like a logical conclusion that since the ventilation rate required per unit tank width decreases with increasing width, less ventilation would be required for a tank with one hood than with two hoods. However, in the case of a tank provided with two hoods the resultant center line velocity at the center of the tank is the sum of the vectorial components of the velocities produced by both hoods as was pointed out by Battista, Hatch and Greenburg.[3] While this value can be estimated with a fair degree of accuracy, it was felt desirable to make actual determinations of the center line velocity across a tank with two hoods so that these values, particularly the minimum control velocity, may be compared with that for a tank with one hood.

Results of Study with Two Hoods

THE same tank was provided with exhaust ventilation through slots along the two long sides and center line velocities were measured with a
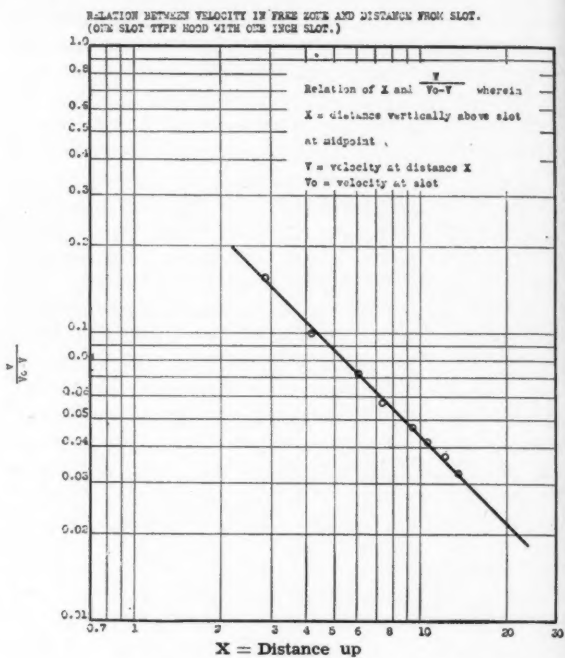
total ventilation rate of 1320 cfm. (660 cfm. through each hood.) The relation between the function $\frac{V}{V_0-V}$ and X is shown in Fig. 5. Since the ventilation characteristics are similar for both halves of the tank, values for only one-half of tank are plotted.

There seemed to be so little difference in the

Effect of slot width upon center line velocity

Relation of X and $\frac{V}{V_0-V}$ for slot widths of 1" and 2" with constant Q

X = distance out from slot along normal at midpoint

V = velocity at distance X

V_0 = velocity at slot

1" slot

2" slot

Center line velocities for two slot widths												
Slot width	Distance out from slot in inches											
	0	1	2	3	4	6	8	10	12	16	20	24
1"±	2210	1014	501	324	240	174	143	121	104	93	86	74
2"±	1460	836	492	337	247	176	143	118	106	95	81	70

X = Distance out

Fig. 4.

minimum center line velocities obtained in the center of the tank with two exhaust hoods and at the remote edge with one hood, that the critical velocities vertically above the center line were determined at several stations for both conditions of ventilation. These results are shown in Table 2. While these results favor the two hoods only slightly, of far more importance is the practical significance: that is, that with one hood any movement by workers or objects near the unventilated side of the tank may cause sufficient conflicting air currents to permit the escape of some of the contaminated air whereas with two hoods the velocity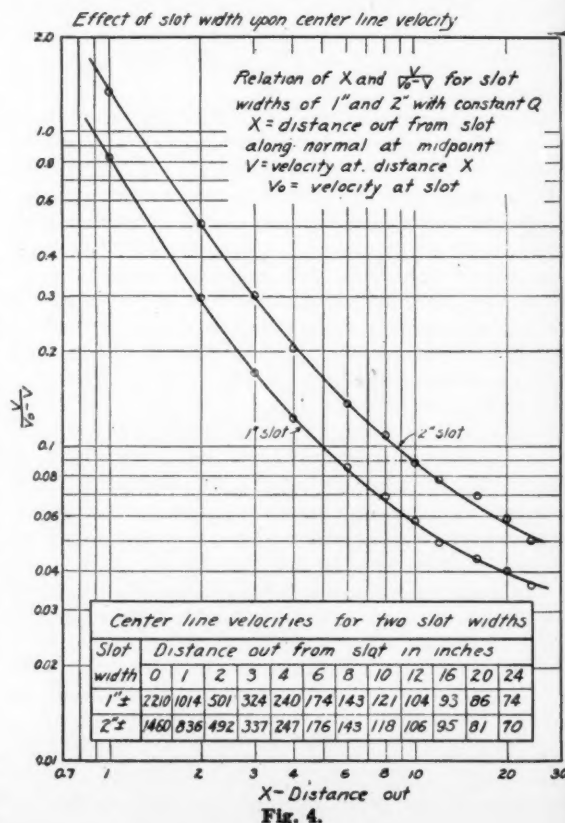 in the zone of probable movement is of such magnitude that no disturbance in the ventilation characteristics is likely.

Conclusions

SINCE the data presented herein essentially substantiate those presented by Battista, Hatch and Greenburg, it seems obvious that the center line velocity across a plating tank ventilated by means of lateral exhaust ventilation varies inversely as the distance from the slot to an exponent less than 1. That is, the ventilation rate required to maintain a given center line velocity over the tank at the point remote from the slot or slots is given by the equation $Q = KVLW^a$ in which the value of "a" is less than unity.

2. Inasmuch as the value of the exponent "a" determined by Battista, Hatch and Greenburg is about 0.6 in which case the tank had no wall opposite the exhaust slot, and the value of the exponent "a" determined in this study is about 0.5, it appears that the equation $Q = KVLW^{0.5}$ de-

fines the ventilation characteristics of plating tanks more accurately than equations now in use. However, since the value of K is unknown and since the equation $Q = 120LW$, first, has been used widely with good results; and, second, gives results essentially the same as the equation $Q = KVLW^{0.5}$ for a critical velocity V of 75 fpm. and for tanks of sizes commonly encountered, it is recommended that it be used pending the determination of the value of "K" and possibly additional data on the characteristics of tanks with two hoods.

TABLE 2.
COMPARISON OF MINIMUM VELOCITIES OVER TANK
WITH ONE SLOT AND WITH TWO SLOTS
(Quantity of Air Exhausted Same In Both Cases)

Number of hoods	Distance from slot	Distance above center line			
		4"	8"	12"	18"
one	24"	65	60	59	56
two	12"	65	70	70	61

3. Since the value of "a" is less than 1, it would appear that the ventilation rate per unit tank width decreases as the tank width increases. In other words, the wider tank is favored. However, this condition will exist only so long as the ratio of the tank length to width is such that the velocity contours in the center line plane passing through the slot as an axis are essentially flat for the greater part of the tank length.

References:

1. BLOOMFIELD, J. J., and BLUM, WM.: Health Hazards in Chromium Plating, Public Health Reports, 43, 2330, 1928.
2. RILEY, E. C., and GOLDMAN, F. H.: Control of Chromic Acid Mists from Plating Tanks, Public Health Reports, 52, 172, 1937.
3. BATTISTA, WM. P., HATCH T., and GREENBURG, L.: New Data for Practical Design of Ventilation for Electroplating, Heating, Piping and Air Conditioning, 13, 2, February, 1941.
4. SILVERMAN, L.: Article about to be published.
5. DALLAVALLE, J. M.: Principles of Exhaust Hood Design, U. S. Public Health Service, Washington, 1939.

Discussion:

MR. L. SILVERMAN (Boston, Mass.): I would like to ask if the exponent of 1.5 that he found in steam exhaust is always a fundamental error?

MR. HATCH: No, as far as I know now. The situation there was of a relatively small hood rather than a relatively long shot. In other words, it comes more nearly into the category of suspension in space, but lengths and widths that are not far apart.

DR. A. J. LANZA (New York): I would like to know whether or not the exponent is determined by the control of velocity and whether the controlling velocity is more nearly perfected by the material you are dealing with or whether it is determined by the shape, and so on, of the exhaust opening?

MR. HATCH: As far as I know, we have no precise quantitative information concerning the control of velocity over plating tanks in terms of direct correlation with performance. Various suggestions have been made all the way, I believe, from a minimum velocity over a tank of 50 feet per minute to a value of 100.

From my personal observation, I should say that the control velocity, minimum velocity within the ventilated

Relation between center line velocity and distance from slot — (Two slot type hoods with one inch slots)
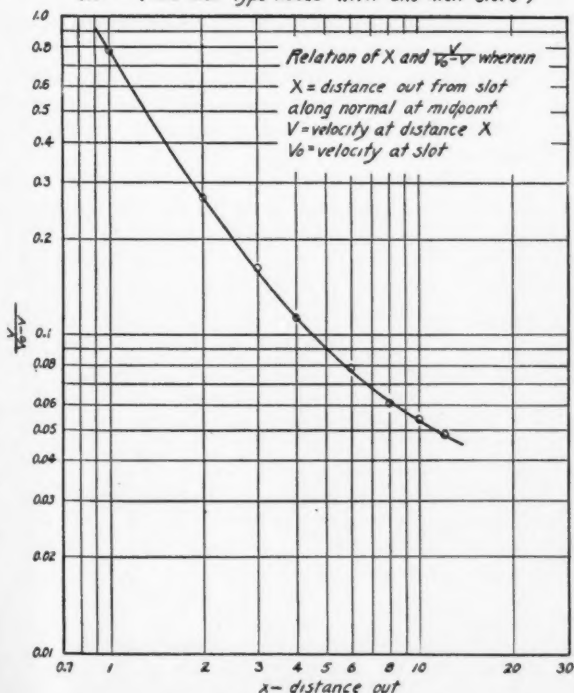
Relation of X and $\frac{V}{V_0} = U$ wherein

X = distance out from slot along normal at midpoint
V = velocity at distance X
V₀ = velocity at slot

x — distance out

Fig. 5.

area, should be a value that is substantially above convection and other stray currents in the room. The plating operation, itself, doesn't send off with any expert force the contamination that is given off over a short distance and then dispersed from that point on by the natural currents in the room. So, the velocity must necessarily be above the expected room velocities; how much higher than that, I don't know.

Experience on other operations would indicate it doesn't have to be much above the minimum, which is usually taken as 50 or 60 feet per minute. In DR. BRANDT's paper he discusses a possibility of a minimum velocity of 75 feet per minute along the central line of the tank.

The Engineering Control of Lead Contaminated Environments

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THIS article will attempt to show a coherent picture of the various factors involved in the detection and control of an environment presumably contaminated by lead. Inasmuch as many engineering survey studies have been, and are being, conducted in various localities we will neglect the general inspection procedure and confine our discussion to some of the various aspects of environmental contamination which have not been emphasized or discussed in the literature.

By its very nature industrial hygiene procedure within any given company from the nation, state, or city-wide survey. The same general information is obtained regarding work facilities and the personnel engaged in a given activity as well as the surrounding environmental influences. However, more detailed and continuous types of information obtainable at frequent intervals over long periods of time enable the investigator to arrive at conclusions and formulate measures which can be shown to be effective by continual follow up. This type of control and follow up should eliminate all but the most exceptional cases of lead absorption and should eliminate entirely cases of clinical lead poisoning.[1] The sporadic survey of the governmental or insurance type perhaps even on the yearly basis is effective in eliminating the bulk of the poisoning cases but does not prevent the occasional case, or group of cases, of damage.

The first essential when complete engineering control is desired is to know when new compounds are to be used or when a previously used lead compound is to be introduced into some new use. This is accomplished through a thorough knowledge of the processes involved as well as the research efforts of the numerous persons and agencies endeavoring to improve those processes. Extensive reading in the trade, patent, and scientific literature, supplemented by personal contact with those engaged in the various researches, is the most feasible way to fulfill this condition in regard to a lead-using or any process involved. Familiarity with the processes in use is, of course, best obtained by spending considerable amounts of time in the plant observing the actual operations. Submitting the changed conditions to the industrial hygienist prior to introduction into production is extremely desirable but not absolutely necessary provided close contact is maintained by the hygienist with the various departments most likely to know of projected developments or responsible for the introduction of new materials.

The second essential is to know how the new use will complicate the environment and to what extent it will affect the employee. This requirement can usually be met by the industrial hygienist by reference to past experience. Lead and its compounds have been so generally studied that some work bearing on the problems to be encountered can be found which will at least give a hint of what to expect in new situations. In addition to the literature various individuals engaged in industrial hygiene have information which may not have been published for various reasons. The exceptions to the above statements which appear when new lead compounds are devised must be handled by a combination of research and close contact with situations where the substance in question is being employed.

This control involves numerous air samples taken with suitable apparatus in the work and adjacent areas, proper analysis of these samples, and a consideration of the time spent by the workmen in the exposed sections. It also involves the examinations of employees by means of the lead in urine and B. A. tests. It has been our experience that these two tests will give adequate warning of increased lead absorption when a number of employees are involved.[2] Clinical examination should not be needed unless the above mentioned control measures fail completely. Inasmuch as we have had no lead poisoning for over five years with over 5,000 employees exposed to lead in various forms we feel that the procedure outlined is adequate.

In amplification of the above, it should be emphasized that enough air samples should be taken at close enough intervals so that a true picture may be obtained. This is also true of the urine and blood samples. Furthermore, the errors involved in the sampling procedure should be clearly recognized and evaluated. These factors as well as the analytical methods involved have been discussed by us in previous publications.[3,4,5,6] (A more recent analytical tool that gives promise of being of aid is the polarograph or dropping mercury electrode.)

Following an evaluation of the extent of the possible exposure the next step is the proper recommendations of an engineering nature which will lead to adequate control at a reasonable cost.

Control Measures

CONTROL methods will be discussed under the five general headings of: (1) Substitution; (2) Change of Operation; (3) Ventilation; (4) General Housekeeping; (5) Individual Protection.
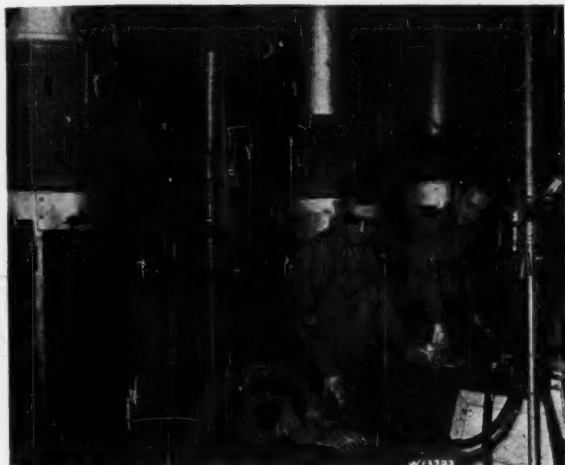
Fig. 1.
Pouring of Stick Solder from Pig

The substitution of other substances for lead is a solution approached with great eagerness whenever difficulties occur and at times a satisfactory solution is reached. However, it should be remembered that lead has unusual physical properties and at the same time is relatively low in cost compared to other materials which will do the same jobs. In most instances the finding of a material which will do the same work at the same cost is hopeless. This does not mean that as new products appear they should not be considered but that the possibilities of success are limited. In a few cases where substitutes suggest themselves they have not been utilized because their adaptation would involve research and testing costs which would make the substitute prohibitive for the limited use that would be involved.

While substitution of other substances for lead, as previously mentioned, is not always successful we might cite an instance where this was quite practical. Analysis of several hundred paints used in the automobile industry had revealed a few
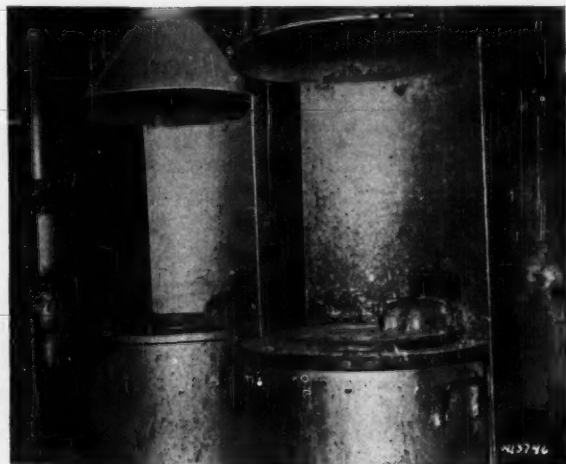

Fig. 2.
Exhausted, Controlled, Lead Melting Pots

which had more than 1% lead content. Paints were formulated which had less than 1% lead content and were found to be satisfactory. At this time no paint used on the passenger cars of this corporation contains as much as 0.5% lead.

In the operations where stud bolts are screwed into engine heads, litharge was used as a cement. Air analysis showed that while no values over 1.5 mg. Pb./10 cu. m. of air were present, when the litharge paste was being prepared the values were at times up to 5 and 6 mg. Pb./10 cu. m. of air with a general average of about 3.5 mg. Pb./10 cu. m. of air. While this was not likely to be serious efforts were made to find a satisfactory substitute. The result was a rubber and non-toxic metal cement sealer which proved very satisfactory. It might also be mentioned that various
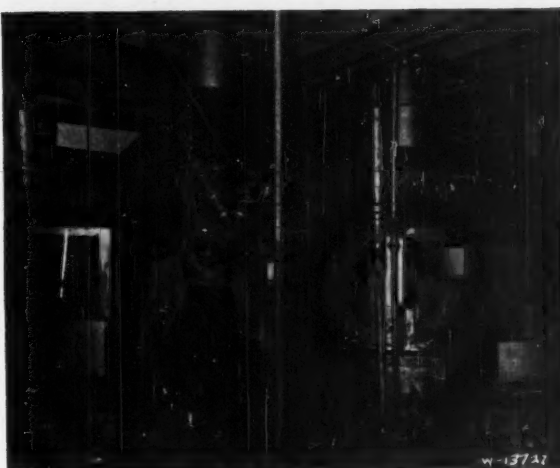
Fig. 3.
Babbit Stock Room. Pouring Reclaimed Solder

efforts have been made to provide a satisfactory substitute for lead solder. Bronze and cadmium have been used, but no great advantages have resulted from such efforts up to the present time.

Often when direct substitution is not possible it may be feasible to change an existing operation. Thus in the case of soldering operations on auto bodies the introduction of hand filing in place of grinding machines materially reduced the concentrations of lead in air. When greater care was exercised less metal was applied and hence less had to be removed. What appeared to be a prohibitive change was actually not so, but a gain in all respects. At the same time greater care was exercised in getting parts to have a closer fit and again less metal was used and a better product was obtained. The use of lead solder was entirely done away with on some operations in this manner.

Perhaps the best example I can give concerns the elimination of mechanical grinding with power-driven grinders. These grinders, sanders and buffers would in the course of removing excess solder filling, deposit in the air up to several hundred mg. of Pb. dust per 10 cu. m. of air per machine. General averages in such areas might

range from 35 to 50 mg. Pb./10 cu. m. of air. The general average when these grinders were removed was reduced from these figures to about 4 mg. Pb./10 cu. m. of air. These amounts were due to hand filing, sanding, to dust on the floors, and to the disturbance of various containers for the chips and dust. Owing to supposed advantages of the power driven grinders attempts were made to solve the problem by building exhausted grinding booths. While some of these were relatively efficient yet the average concentration of lead in the air varied from 50 mg./10 cu. m. to several hundred mg. on some installations. Even when approved respirators of high efficiency were used the quantities were such that a well fitted filter respirator would let in from three to five mg. Pb./10 cu. m. of air, and when the careless worker was considered this exposure would be much higher. One solution, which was successful, was to place an air supplied hood over the mechanical respirator. Since constant and close control was needed for these booths at all times and since it had been demonstrated that careful filling of seams and removal of the excess solder by hand filing was extremely practical at no cost penalty, all such booths were removed. The booth system was practical but required such close ob-

Fig. 5.
Exhausted Hoods over Solder Reclaiming. Body in White Area

Pb./10 cu. m. of air. These samples were taken within five feet of the exhaust and the lead dust being swept up was 15 feet away, with a concentration of less than 0.5 mg. Pb./10 cu. m. of air. The wet sweeping was only partially effective in that clouds of lead dust were raised when the floor was sprinkled; one high test showed the level to be raised from 1 mg. to 6 mg. When complete wetting took place the wooden floors were too slippery from the safety as well as the health standpoint.

Hence a fixed vacuum system was installed with 80 service inlets. These service inlets were connected to two Hoffman exhaust units each consisting of a primary collector of 47 cu. ft. effective dust capacity and a secondary 48 in. by 96 in. having 316 sq. ft. of bay area. When six lines were open simultaneously they would handle 480 cu. ft. of air at 7 in. vacuum behind a ⅞ in. orifice.

The introduction of vacuum cleaning reduced the lead concentration in most areas to less than one mg. Pb./10 cu. m. of air. In some areas where

Fig. 4.
Dust Collector for Vacuum Sweeping System. Body in White

servation that it constituted a perpetual mental hazard to the industrial hygiene personnel. It was a certainty that the carelessness of individuals would cause occasional slips over a long period of time.

The residual lead dust in the air was due to a large number of items which might be called the housekeeping and ventilation influences. Tests showed that in some filing and finishing areas the dust on the floor was an important factor. Tests were made with a portable collector type of vacuum cleaner and with wet sweeping. The bag filters were not sufficiently effective in the two machines examined since one collector gave off 5.5 mg. Pb./10 cu. m. and the other 17 mg.
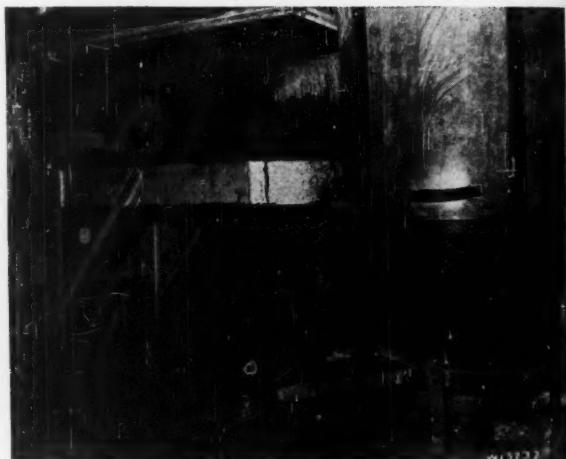

Fig. 6.
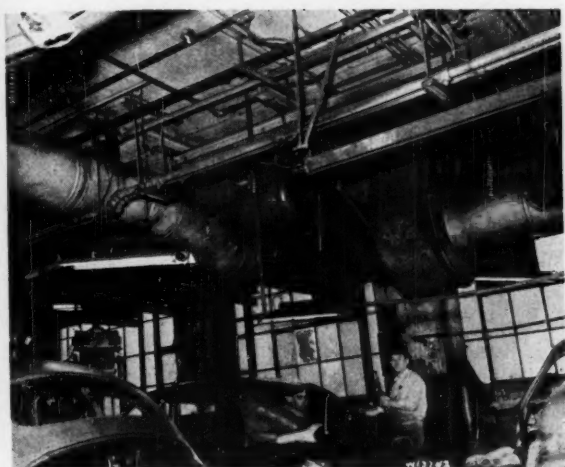**Vacuum Sweeping of Floors Body in White**

Fig. 7.
One of Four Main Exhaust Lines. Body in White

air hose and ventilators were in use the average concentration remained around 3 mg. and in a few cases higher. These were corrected by the use of vacuum cleaning instead of air blowing, the elevation of air ducts opening to waist level, and the lowering of the velocity of the air stream. These measures reduced the average concentration in the filing areas to less than 0.3 mg. Pb./10 cu. m. of air.

In the torch soldering areas adjacent to the filing areas following the above corrections, the average level was still about 1.5 mg. with some values as high as 5 mg. Tests showed that a small part of this concentration was due to unhooded lead pots. Installation of hoods and thermostatic controls on all lead pots and heating pans reduced this average to 0.7 mg. with no values over 1.5 mg. Pb./10 cu. m. of air. All exhausted hoods required 25,000 cu. ft. of air per minute with a velocity of 2,500 linear feet in the pipes. This air movement effectively removed the lead fumes from the torch soldering operations even though no changes were made. For five years the average level in this department with almost 3,000 workers exposed has been maintained at less than 0.5 mg. Pb./10 cu. m. of air and no single value has been found higher than 2.1 mg. Pb./10 cu. m. of air.

Along with the previous subject of change of operations goes the matter of improved housekeeping. Such measures as: vacuum cleaning of floors, walls and rafters; the placing of covers on skid carts, buckets and other containers for leaded dusts; and provisions for personal cleanliness; all contribute to the control of possible lead exposures.

The previous example should suffice to explain control measures of a housekeeping nature as well as change of operation type. In addition, it should be noted that while it seems true that oral ingestion of lead oxide is relatively unimportant, provisions are made for the employee to wash with a suitable soap powder of our specification before meals and when leaving work. In battery plants

and operations where organic lead compounds are used, personal hygiene becomes more important and in some cases provisions for proper protective clothing is necessary. This situation described provides an example of control which has not failed and hence does not require such measures as supplying calcium in the form of milk, nor is any other form of corrective treatment needed. Other palliative measures, such as transfer of employees, indicative of failure, are also not required, nor is any form of personal protection necessary.

Inasmuch as the dust or fume in the air is the largest single factor to be considered, and when the above mentioned factors are not sufficient in themselves to insure safety, the use of proper exhaust ventilation becomes the most important consideration. Specific cases will be dealt with later but it has been our experience that the excessively high velocities and volumes sometimes recommended are not necessary. This conclusion has been reached on the basis of plant experience and through use of experimental set ups for hood design and velocity studies. The various theoretical formulas governing such installations are usually generalizations which do not apply to the specific instances as they are encountered in practice. I do not imply that some of the less specific results of these generalizations are not valid, but that, when formulae are used on any one job they may fall down due to the specific influences surrounding that particular installation. The studies on contour lines escape velocities, etc., leading to increased use of proper size flanges, the restriction of openings to insure higher velocity, and the placing of hood openings as close as possible to the dust producer, are fundamentally important, and will apply to nearly all installations.

However, the attempts to calculate the volumes needed on a given installation with known velocities are subject to such external influences as variable air currents, opened windows and doors, and changes in temperature in the operation itself. In such cases experimental set-ups duplicating the
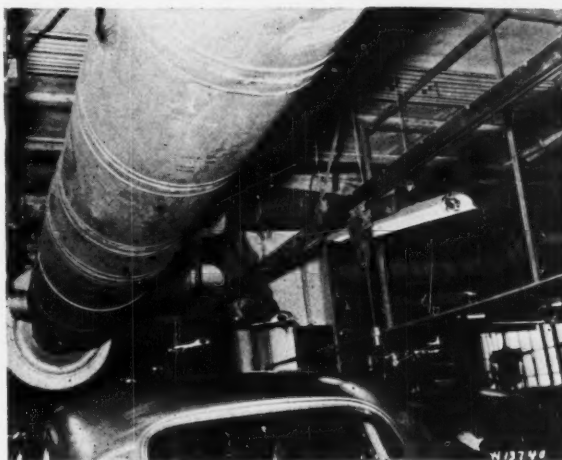

Fig. 8.
Exhaust Main. Body in White

existing conditions are more feasible than the setting up of a complicated equation which may not work the next time. It is for these reasons that some equipment with properly designed (in a general way) exhaust equipment attached to the machinery must be redesigned when placed in operation. Some exhaust ventilation applications to lead problems will be considered later.

Personal Protection

AFTER all the previous considerations have been applied there are always some problems that demand personal protection. This may be because of the impossibility of fully utilizing the other measures or because it is the only economical thing to do.

Approved filter respirators for lead dust may be resorted to, if no toxic fumes or vapors enter into the picture. While some of these devices are now developed to the point where the breathing resistance is very low there is still enough resistance so that work efficiency is reduced. In addition, there is the problem of getting the employee to properly wear the equipment provided. In many cases this factor can only be overcome by the continuous supervision and education of the employee.

There are other situations where it is more satisfactory to wear an airline respirator. These devices require the carrying of a hose line and should include a source of himidified, low pressure air separate from the high pressure lines. When high pressure air is used oil, gases, or toxic dust may accidentally be introduced into the worker's breathing zone. This protection can be provided either in a gas-tight face-piece type or in a hood enclosing the whole head.

In situations where solvents, lacquers, etc., may be included with lead pigments a combination of a hood open around the eyes, such as we developed in about 1935, and an approved lead filter respirator may provide the only satisfactory means of keeping the filter from plugging up and withal getting complete protection.

This concludes the general discussion of the factors involved in the engineering control of lead contaminated environments. We will proceed to the investigation of examples where such control measures were used after stating that the check up on control measures involving the application of investigative procedure at intervals following the installation of such measures as seemed suitable is the only way of finding out whether or not the control measures were satisfactory.

Ventilation

WHILE we have previously considered situations where ventilation was one of the corrective factors we will now consider several situations where exhaust ventilation is the sole corrective measure. We have mentioned the exhaust hoods over lead solder melting pots in another section, but it should be emphasized that the control of temperature and the hooding of these pots were not of paramount importance. Our conclu-

sions as a result of numerous tests on various kinds of lead melting pots, are essentially those reported by Tebbins* several years ago. Usually the temperature of the pots does not go so high as to make the lead vapor the major factor. Even in the extremely large pots, used in heat treating, where temperatures up to 1800°F may be used, the most important factor is the lead oxide in the form of dross. The more the metal is agitated the larger the quantity of lead oxide. Low velocity air is all that is needed though often more air is moved than theoretical calculations will show to be necessary, due to other materials as solder flux being present and causing the system to "block up" unless a fairly large pipe size and pipe velocities of 2,000 to 3,000 feet per minute are used.

Soldering operations themselves when concentrated in a small area with little air movement may evolve lead fumes up to 6 mg. Pb./10 cu. m. of air. This is not invariable as 2.5 to 4 mg. seems to be more nearly an average value. One or two men using soldering irons on small objects may cause lead concentrations of 2 to 2.5 mg. within three feet of the operation. Usually a slight rise in the velocity of air movement in the surrounding area will reduce this concentration below 1.5 mg. When numerous soldering irons are in use, coupled with other lead exposures, local exhaust ventilation close to the work is needed. If placed within six inches of the work, a face velocity of 200 l.ft.m will usually be adequate.

The important factor in soldering operations is the heating furnace for the irons. Each time the iron is used and replaced in the furnace it carries back a small amount of lead. Eventually a small puddle of lead is formed in the furnace. This, particularly in gas-fired furnaces, is dessiminated into the surroundings at such a rate that one furnace may contribute enough lead to give a concentration of from 15 to 20 mg. Pb./10 cu. m. of air five feet from the furnace. In general, such operations have from 5 to 15 mg. within five feet. The small pipes sometimes placed on these furnaces to take gaseous products away are totally ineffective and the proper remedy is to build an exhaust hood open at both ends around the entire furnace.

Another case where lead would not be expected is the seam welding of metal containing as little as 2% lead. Many of these seam welders operate with a stream of water as a coolant. Tests made three feet above the operation in the column of steam showed lead concentrations up to 12 mg. Pb./10 cu. m. of air. The average concentration was about 10 mg. However this does not create a hazard unless the employee must during some operation get in this cloud of steam as practically all of the lead concentrates in this area. Ten feet away from the operation with no exhaust ventilation and less than 70 l.ft.m. general air movement shows no values above 1.5 mg. It should be permissible in such a case to increase the air move-

*In the *Journal of Industrial Hygiene and Toxicology*.

ment around the specific point of generation of fume as the total volume of lead is so insignificant that 200 l.ft.m. directed at the column of steam will reduce values 12 in. from the operation to less than 1.5 mg. Pb./10 cu. m. of air. All samples of fume were collected with the electrical precipitator.

Impinger samples were about 55% less.

Another example of unexpected lead contamination is found in the drilling of brake lining. Various linings had from 2.5 to 14% lead content of the total brake lining. In the following discussion the material was found to have 2.6% Pb. The lead in air concentration ranged from 3.5 to 11.8 mg. over a 2,500 sq. ft. area. The samples were collected with the impinger as approximately the same values were obtained as with the electrical precipitator.

In the above installation it was decided to remove only the air-borne dust because of the large amount of heavy drillings produced. It was recommended that face velocities on the various hoods should be limited to 700 linear ft./min. The check up showed no values over 0.5 mg. Pb./10 cu. m. of air and the installation cost about one-seventh as much as a complete removal system. This system has been in operation over two years and no concentrations over 2.1 mg. have been found on our routine 90-day check up. Furthermore, less than 3% of the tests were over 1 mg.

Summary

THE foregoing account is in effect a condensation of the results obtained, on some aspects of a general lead problem, over a period of time exceeding five years. The procedures described and the results obtained in the control of lead contaminated environments are briefly summarized for certain types of process. The successful use of the procedures outlined is indicated by the excellent results.

Bibliography:

1. HARROLD, G. C.: Methods of Industrial Hygiene Procedure and Testing. *ASTM Bulletin*, p. 19, August, 1939.
2. MEEK, S. F., COLLINS, G. R., and HARROLD, G. C.: Correlation Coefficient Between Basophilic Aggregation Test and Lead in Urine. *J. Ind. Hyg. & Tox.*, Vol. 22, No. 9, November, 1940.
3. HARROLD, G. C.: Industrial Hazards, Methods of Detection and Maximum Allowable Limits. Michigan State Wide Safety Conference, 1938.
4. HARROLD, G. C., MEEK, S. F., and HOLDEN, F. R.: A Practical Method for the Rapid Determination of Lead When Found in the Atmosphere. *J. Ind. Hyg. & Tox.*, Vol. 18, No. 10, December, 1936.
5. HARROLD, G. C., MEEK, S. F., and HOLDEN, F. R.: Note on A Practical Method for the Rapid Determination of Lead When Found in the Atmosphere. *J. Ind. Hyg. & Tox.*, Vol. 20, No. 9, November, 1938.
6. HARROLD, G. C.: Industrial Hygiene Laboratories and Their Work. *Indust. Med.*, Vol. 6, p. 342, June, 1937.

THE Third Annual Meeting of the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION will be held at Cincinnati, Ohio, April 13-17, 1942, in conjunction with the Twenty-Seventh Annual Meeting of the AMERICAN ASSOCIATION OF INDUSTRIAL PHYSICIANS AND SURGEONS.

Comparison of Rapid Methods for Quantitation of Impinger Samples of Granite Dust

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A SERIES of impinger samples collected during routine investigations of dustiness at granite plants was examined simultaneously by (1) the standard light-field count, (2) Spencer hemacytometer cell count, (3) dark-field count, and (4) photo-electric measurement of light intercepted vertically by a column of the liquid. (The methods used are described in Appendix 1.) It was thought that the interrelationships of the determinations by the four methods might give clues to the reasons for discrepancies between one or another of the more rapid methods and the standard light-field count. Variations of the hemacytometer cell count from the standard might be expected to be due to factors other than size of particles, while the dark-field count minus the light-field count would give the number of fine particles discernible between the resolving powers of the two optical systems and hence an indication of the size-distribution of the dust that might be expected to affect the photo-electric measurement, while differences in photo-electric measurements for two samples of one kind of dust with equal counts might be due primarily to differences in particle size, and consequently, explainable by the differences in ratios of dark-field to light-field counts. It was hoped, furthermore, that correlations of one or more of the more rapid methods with the standard could be established at least for samples taken under similar conditions so that subsequent samples could be quantitated rapidly with the use of previously prepared calibration curves for conversion to the standard count.

As might be anticipated from so simple an extension of routine field determinations not all of these relationships were amenable to derivation without facilities for a real research study, but it is felt that some of the observations and data are worth describing and recording.

The mean of all hemacytometer cell counts on samples taken on the original set of 35 samples at the granite plants was 1.18 times that of the standard light-field counts. By dividing each hemacytometer cell count by 1.18 and comparing it with the corresponding standard count it was found that a very good correlation existed. (See Appendix 2, Table I, Cols. 1 and 2, and Appendix 3.) From the miscellaneous samples of air near

various tools, of general shed air both dusty and fairly clean, and of relatively clean air near plants it was evident that the adjusted hemacytometer cell count justifiably may be substituted for the standard for most types of investigations of dustiness within the range of this study, with great saving in time and eye-strain.* None of the many other attempted correlations of one method against another, or against results to which were applied trial factors indicated as possibly likely to level out variations due to differences in particle size, gave nearly so good a correlation. A subsequent set of 18 samples at granite plants, and another set of 32 at foundries likewise gave very good correlation between the hemacytometer cell counts and the standard when the former were divided by 1.23 and 1.27, respectively, instead of 1.18. (See Appendix 3.)

It should be noted, however, that another series of 16 samples taken at granite plants from various sources like those described in Appendix 2, but upon which only the hemacytometer cell counts and measurements of light intercepted were made, all appeared to run too high for the counts or too low for the light intercepted. (See Appendix 3, Table II, also Appendix 4, Fig. 3, Curve 1.) The results from this set of 16 samples, all obtained during one period of time within which none of the other 85 samples showing the consistent results was analyzed, might be taken to tend to nullify the general conclusions, but careful consideration of all the work leads us to believe that the more probable explanation is that an obscure error crept into this series.

The supposition that, in general, the ratio of the dark-field count to the light-field count is an indication of the fineness of the dust was not borne out by attempts to correlate this ratio against tentative indications of particle size such as the amount of light intercepted per million light-field particles, or per million dark-field particles, or again, per million light-field plus dark-field particles modified by various trial estimates from assumptions based on trends and designed to give weight to fractions of the total dust in accordance with some reasonable expectancy of the amount of light which the fractions would intercept. In fact, all attempts to find a good correlation between the different methods by applying factors to take into account size-distribution, as well as attempts by trial-and-error to weight the four methods of determination into a smooth-curve type of relationship yielded but indefinite results. While one attempt to achieve the latter result produced a remarkably smooth curve which from the four parameters would predict very closely the photo-electric measurement, the fact that the photo-electric measurement itself was one of the variables, and that as successive trials increasingly gave this factor greater weight, the formulas, though they became increasingly accurate for calculating, by means of the four variables, the light intercepted, at no stage of the trial-and-error progression could be reversed so as to give con-

* Barnes'[7] results, summarized in Appendix 3, indicate that there are limitations which must be considered.

sistent calculations for any of the three methods of counting. In other words, while the indications were that definite relationships did exist, the attempt to state them mathematically for practical use did not succeed. It had to be concluded that one or more of the methods was not consistent with respect to inclusion of particles enumerated within the size ranges which it might be expected to encompass. The result of these trials and studies was a conviction that an attempt to relate count, light-intercepted, and particle-size distribution as determined from an approximate and not too time-consuming adaptation of one or another recommended method of determining sizes, preferably the tyndallometer method as described by Hatch and Choate,[8] if preliminary exploration should indicate that good correlations might be forthcoming, should be made by someone with the necessary facilities for the research. Establishment of quantitative relationships of factors affecting the various methods of dust determinations in common use would be valuable not only in dust technology but also in problems of turbidity of water, characteristics of clays for ceramics, in soil mechanics, abrasives, etc. There is a reasonable likelihood that several photo-electric measurements could be worked out for transmitted and reflected light for integration by a series of pre-established calibration curves to give very rapidly a good estimation of both count and mean particle size. (See Appendix 6.)

For the original set of 35 samples subjected to the four determinations a fairly good correlation, with few exceptions of individual samples, was found to exist between the light intercepted and the standard count. (See Appendix 2, Table 1, Columns 1 and 4, and Fig. 1; also Appendix 4.) The measurements of light intercepted plotted against the standard counts gave a curve from which could be read from a measurement of light intercepted a corresponding count close enough for considerable practical use where rapid, on the spot, explorations of dustiness were wanted. There appears to be a use for these photo-electric measurements where a time-integrated rapid determination is desirable instead of the grab samples in common use for such purposes, or where rapid estimates are desirable on samples collected with the same instrument as is used to obtain standard counts. Also, it appears that there is as much justification for the use of the photo-electric measurement on the basis of correlation with the standard count as for the current use of the Owens-Hatch, Konimeter, or Bausch and Lomb sampling instruments. (See Appendix 5.)

CONCLUSIONS: Comparisons of three methods (advocated for determinations of dustiness more rapid than the standard) with the standard light-field count indicated that the hemacytometer cell count and the photo-electric determination of light intercepted by a column of the impinger liquid could be used with judgment under the limitations described to reduce materially the time required for routine investigations. Suggestions are made for a possible method of approach for development of rapid photo-electric determinations to give ap-

proximate estimates of count and size of particles to explain discrepancies encountered with present methods and to extend the scope of use to which the more rapid methods may be put. It is further suggested that the hemacytometer cell count be given wide trial and serious consideration for adoption as the standard method.

Appendix 1

DESCRIPTION of Methods Used. (1) The Standard Light-field Count. The method used was that described by Bloomfield and DallaValle (1935)[1] with the following exceptions. A Spencer microscope lamp of 100 watts was placed 8 inches from the sub-stage mirror. This gave brighter illumination than is used by most observers whom we have questioned. It is our experience that more particles are counted by the brighter light since with dimmer light the smallest visible particles are apt to be missed. It is possible that our lower counts obtained with the standard method than with the hemacytometer cell as compared with essentially the same counts by each method reported by Williams[2] may be due to his use of a sub-stage lamp with more consistently optimum illumination. The mean ratio of 18 hemacytometer cell counts to standard light-field counts reported by him was 1.15 as against a mean ratio of 1.23 for all Rhode Island samples of granite and foundry dusts. (See Appendix 3.) Also, a Hatch cell of 0.25 mm. depth was used instead of a Sedgwick-Rafter cell of 1 mm. depth, and a minimum of five minutes was allowed to settle the dust in the cell. The recommendation of the A. P. H. A. Sub-Committee on Dust Procedures in Air Analysis[3] to settle cells a much longer time when successive fields show a tendency to increase in count was not followed, this being unknown to us at the time.

(2) Spencer Hemacytometer Cell Count. The method followed was that advocated by Williams.[2] The same comment as to illumination used as noted for the standard count may be in order but the difference from the lamp used by Williams may not be significant for the hemacytometer cell.

(3) Dark-Field Count. The method used was that described by Hatch and Pool.[4]

(4) Photo-electric Measurement of Light Intercepted. The method used was an approximate copy of that described by Cadden and Roetman[5] and amplified by letter and diagram.[6]

The apparatus as copied (See Diagram 1) consisted of a light-proof box containing a 50-watt bulb located above the dust suspension contained in a 50 cc. short-form Nessler tube. A Weston Photronic Foot-Candle Meter was incorporated in the box under the Nessler tube so that the light passing through the suspension strikes the photo-electric cell, the dial for reading the foot-candles

Diagram 1. APPARATUS USED FOR MEASUREMENT OF LIGHT INTERCEPTED
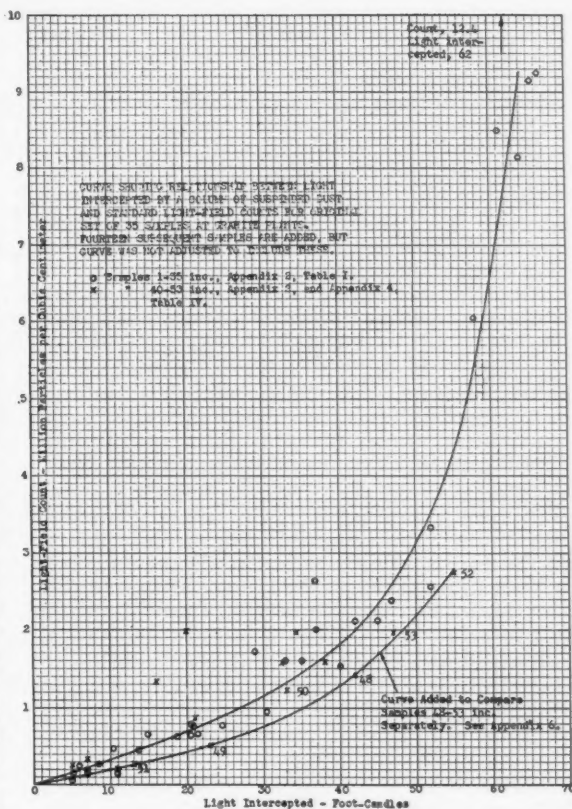(After Cadden and Roetman [5,6])
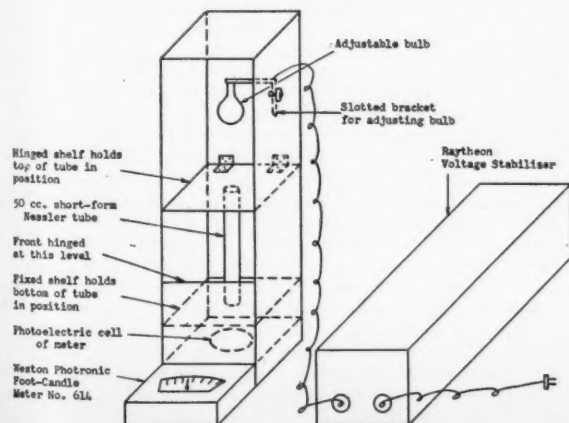
Fig. 1.

being located outside of the box. The overall dimensions of the box are 5½ inches square and 20 inches high. The distance from the bottom of the bulb to the liquid level in the Nessler tube is approximately four inches, the distance from the liquid level to the bottom of the Nessler tube is 5 $\frac{1}{16}$ inches, and the fixed distance between the bottom of the Nessler tube and the exposed surface of the photronic cell is 1 $\frac{1}{16}$ inches. The bulb may be raised or lowered by means of a wing nut connected to the angle iron holding the elecertic socket to permit of adjusting the "zero" setting on the meter for the distilled water blank prior to and subsequent to taking the readings on the samples. We used 80 foot-candles as the "zero" settings, since this gave a convenient working range. In order to maintain constant voltage, without which variations in meter readings would take place with fluctuations in the voltage, a Raytheon Voltage Stabilizer with a constant output of 115 volts over an input range of 95 to 130 volts was used.

To read samples it is but necessary to fill the Nessler tube with dust-free distilled water, insert the tube in the box, turn on the light, and raise or lower the bulb until the meter reading is 80. A tube containing a suspension of dust is then inserted, the light turned on and the reading taken. The light intercepted by the column of dust-suspension is obtained by subtracting from the "zero" setting of 80 foot-candles the reading for the samples.

Appendix 2

SOURCES of Samples and Results of Comparative Determinations by Four Methods. Samples No. 1 to 35 inc., examined by four methods simultaneously; Nos. 36 to 53 inc., by two or three methods simultaneously, including light-field counts; and Nos. 54 to 69 inc., examined by hemacytometer cell counts and measurements of light intercepted were all collected at or near granite plants from sources as follows:

General outdoor air, nos. 9, 24.
General shed air, nos. 13, 16, 40, 41, 69.

Quarry operations, nos. 63, 64, 65.

Air near carborundum blast chamber exhaust, no. 23.

Abrasive blasting, nos. 18, 22, 27, 43, 44.

Plug drilling, nos. 5, 42, 47, 56.

General air near tools, nos. 2, 28, 39, 50, 67.

Surfacers, 4 point, nos. 6, 38, 45, 46, 57, 60.

Surfacers, bush hammer, nos. 1, 29, 36, 54, 59, 61, 68.

Hand-pneumatic tools 4 point, 9 pt., 16 pt., nos. 3, 10, 12, 17, 30, 31, 34, 35, 48, 51, 52, 55, 66.

Hand-pneumatic chisels, nos. 4, 7, 8, 11, 14, 15, 19, 20, 21, 25, 26, 32, 33, 37, 49, 53, 58, 62.

(Note—Nos. 30 and 31, 32 and 33, 34 and 35 are in reality three samples split into six for analysis.)

The results of determinations by four methods simultaneously are given in Table I of which column 4 is converted from Fig. 1 in which a curve is derived from light-field counts plotted against photo-electric measurements of light intercepted .

TABLE I.
RESULTS OF DETERMINATIONS ON SAMPLES AT GRANITE PLANTS BY FOUR METHODS

| | Million Particles Per Cubic Foot | | | |
| | Col. 1 | Col. 2 | Col. 3 | Col. 4 |
Sample No.	Light-Field Count	Hemacytometer Cell Count Divided by 1.18	Dark-Field Divided by 10*	Count Estimated from Curve of Light Intercepted vs. Light-field Count
1	68.8	74.8	31.7	79.
2	5.4	6.2	7.5	6.5
3	88.	96.9	84.5	92.5
4	114.	126.	119.5	104.
5	87.9	75.	115.8	98.7
6	466.	445.	323.	292.
7	27.1	28.8	29.4	25.7
8	3.0	3.1	1.3	2.2
9	0.9	0.6	1.2	1.6
10	303.	320.	204.5	363.
11	84.4	89.	96.3	89.4
12	94.5	90.7	102.	86.2
13	11.2	11.2	12.8	11.2
14	47.2	46.6	32.1	51.6
15	72.	74.7	61.4	42.1
16	4.7	4.5	3.0	4.4
17	237.	243.	199.	166.
18	9.8	9.4	4.0	10.4
19	3.2	3.1	3.0	3.2
20	9.9	9.9	6.0	8.7
21	8.2	8.2	6.1	8.8
22	2.2	2.0	1.3	2.7
23	11.4	11.3	27.3	14.3
24	0.64	0.5	0.6	1.9
25	101.6	102.3	110.8	81.
26	23.4	21.9	13.9	24.5
27	11.0	10.9	7.2	12.4
28	422.5	393.	206.	363.
29	4.2	4.9	10.2	9.8
30	44.3	44.1	40.	28.7
31	44.3	44.1	40.	44.3
32	64.8	66.	59.	53.8
33	64.8	66.	59.	89.2
34	202.9	198.2	162.5	148.
35	202.9	198.2	162.5	123.

*The approximate mean of ratios of dark-field to light-field counts.

For identification of the samples plotted in Fig. 1 the points are listed starting with the highest count for each reading for foot candles of light intercepted, as follows:

Ft. Candles	Nos.	Ft. Candles	Nos.
5	44, 31, 24	32.5	47
6	34	33	32, 50
7	41, 22, 33	34.25	40
8.5	19	35	12
10.5	17	37	35, 25
11	9, 29	38	46
13	51	40	2
13.75	26	42	7, 48
15	8	45	14
16	43	46.7	11
18.75	13	47	53
20	42	52	3, 15
20.5	20, 16, 18	55	52
21	45	58	4
21.25	21	61.25	28
23	49	62	6
24.75	27	64	5
29	30	65.5	1
30.5	23	66.75	10

Appendix 3

COMPARISONS of Hemacytometer Cell Counts and Standard Light-field Counts. Summarized in Table II are all the comparisons of hemacytometer cell counts and light-field counts of which we have record, including those of Williams[2] and Barnes.[1] The latter's samples were collected in an M.S.A. Electrostatic Dust Sampler, and in the cases of the extreme ratios the necessary checks were not possible.

Appendix 4

COMPARISONS of Measurements of Light Intercepted vs. Light-field Counts. For samples 1-35 inc. these comparisons are shown in Appendix 2, Table I, Columns 1 and 4, Fig. 1; samples 40-53 inc. are identified in Appendix 2, plotted on Fig. 1, and tabulated in Table IV.

The mean error of the original 35 determinations from light intercepted, using the curve in Appendix 2, Fig. 1, as compared with the standard light-field counts was ±27%. The mean error for the 14 samples subsequently added was ±37% but this was obtained by comparison with the original curve: the curve was not adjusted to include the 14 samples added. The curve was drawn by eye.

The same comparisons were made for the samples collected at foundries. These were Nos. 70-79 inc. of Appendix 3, Table III-A. In Table V and Fig. 2, following, are given the results derived from a separate curve for this type of dust.

The mean error for determinations from light intercepted for these 10 foundry samples, using the curve in Fig. 2, following, as compared with the standard light-field count was ±17%.

A summary of all of our curves for counts vs. light intercepted is shown in Fig. 3 together with those reported by Cadden and Roetman[5] with their data adjusted to be comparable in general terms. To make this adjustment their values for light intercepted were multiplied by

$$\frac{80}{118}$$

since their "zero" reading for distilled water was 118 and ours 80. While the ratio may not be strictly proportional as denser suspensions of dust are reached, and the instruments used would require corrections for factors to account for small differences in construction, the resulting comparisons of trends are believed to be of interest. Curve No. 1 of Fig. 3 represents the series of 16 samples into which we believe an error had crept to make it different from curve No. 3 to Fig. 3 as explained on p. 44.

The divergent curves for different dusts emphasize the need for proceeding with measurements of light intercepted on the basis of calibration curves for each type of dust and set of samples.

Appendix 5

COMPARISONS of Validity of Measurements of Light Intercepted by Impinger Samples with Counts from Grab Samplers. Since it is accepted common practice to use grab samplers such as the Konimeter, Owens, and Bausch and Lomb instruments an attempt was made to compare the validity of determinations deduced from the measurements of light intercepted with that of those instruments on the basis of correlations with the standard light-field impinger counts which have been shown to correlate with physiological effects when magnitude of exposure is taken into account. The published information on these comparisons with the standard instrument appears to be surprisingly scant. The Journal of Industrial Hygiene and Toxicology was searched from Vol. 1, 1919, to date, as were all U. S. Public Health Service Bulletins (1925 to date), and Public Health Reports (1916 to date). Sundry individuals who were known to have made comparative determinations were asked for data and suggestions, but most of them had not made their determinations under conditions to allow publication for the purpose intended. It is desired to acknowledge communications containing data and helpful suggestions on

TABLE II.
SUMMARIES OF COMPARISONS OF HEMACYTOMETER CELL COUNTS AND STANDARD LIGHT-FIELD COUNTS

Number of Samples	Sources	Ratios: Hemacytometer Cell Counts to Standard Light-field Counts		
		Maximum	Minimum	Mean of ratios
WILLIAMS:				
18	Foundry- tri-calcium phosphate, silica, talc, and grinding dusts	1.67	0.78	1.15
BARNES:				
4	Iron Foundry, A	5.25	2.00	2.92
8	Iron Foundry, B	6.28	0.71	2.76
3	Porcelain Plant	2.22	1.21	1.67
15	All data	6.28	0.71	2.58
RHODE ISLAND: Direct Comparisons				
35*	Granite, original set	1.38	0.78	1.18
18**	Granite, additional	1.39	1.07	1.23
32***	Foundries	1.88	1.08	1.27
85	All R. I. data	1.88	0.78	1.23
RHODE ISLAND: Comparisons with Light-field Counts Estimated from Measurements of Light Intercepted, Fig. 1, Appendix 2.				
16	Granite, misc. sources	6.12	1.50	2.77

*Samples No. 1-35 inc.; **Samples Nos. 36-53 inc. (Appendix 2); *** Samples Nos. 70-101 inc. (Appendix 3, Table III).

Table III-A gives the sources and Table III-B the comparisons for each of the 32 samples taken at foundries.

TABLE III-A.
SOURCES OF FOUNDRY SAMPLES

Department or Operation	General Air	Operators' Breathing Zone
Main Foundry	71, 73, 83, 88	70, 72, 80, 82, 86, 100
Molding	75, 90, 95	81, 85
Core making	77, 78	84, 91, 92, 96, 97
Sand mixing	76	74, 99
Shakeout	87	89, 98, 101
Snagging	79	93
Sandblasting	94	

TABLE III-B.
COMPARISONS OF COUNTS ON FOUNDRY SAMPLES MILLION PARTICLES PER CUBIC FOOT

Sample No.	Light-field Count	Hemacytometer Cell Count Divided by 1.27	Sample No.	Light-field Count	Hemacytometer Cell Count Divided by 1.27
70	4.13	4.92	86	1.03	1.23
71	1.65	1.41	87	2.8	2.46
72	5.93	5.41	88	16.9	16.1
73	2.09	1.89	89	12.6	13.0
74	4.94	5.4	90	1.9	1.88
75	0.94	0.93	91	7.25	7.03
76	1.67	1.55	92	11.7	11.4
77	4.69	4.67	93	312.	304.0
78	0.73	0.78	94	38.6	38.7
79	23.1	21.5	95	1.81	1.97
80	0.36	0.33	96	1.98	1.97
81	0.88	0.82	97	3.03	2.87
82	3.63	3.44	98	42.6	42.0
83	0.39	0.33	99	43.4	64.1
84	3.67	3.54	100	1.98	1.93
85	0.73	0.77	101	6.88	7.36

the problem as a whole from Barnes,[7] Stratton,[9] Brown,[10] Hatch,[11] Hazard,[12] Drinker,[13] Williams,[14] Rothmann[15] and Coleman,[20] and help by Broomfield[16] with whom the problem was discussed during the conduct of the study.

The net results of the comparable data are given in Table VI. The Owens-Hatch instrument was a modifica-

TABLE IV.
ADDITIONAL COMPARISONS OF SAMPLES AT GRANITE PLANTS FOR COUNTS ESTIMATED FROM LIGHT INTERCEPTED VS. LIGHT-FIELD COUNTS

Sample No.	Million Particles Per Cubic Foot	
	Counts Estimated from Curve of Light Intercepted vs. Light-field Count	Standard Light-field Count
40	15.8	22.0
41	2.7	4.1
42	15.2	44.6
43	21.6	53.8
44	3.5	5.7
45	11.3	13.4
46	62.0	59.6
47	31.2	38.0
48	52.5	37.5
49	21.1	13.7
50	7.1	6.4
51	12.3	8.1
52	203.0	128.5
53	123.0	93.3

tion of the Owens instrument designed to correlate a rapid method with impinger counts. The table is self-explanatory upon inspection and is believed to reveal as much justification for the use of the measurements of light intercepted as for the current use of the grab samplers, within the limitations described in the text.

Appendix 6

INDICATIONS of Effect of Particle Size-Distribution on Validity of Counts Derived from Measurements of Light Intercepted, and Possible Approaches for Anticipating this Effect. Following the failure of the attempts to deduce from the comparisons of the four methods a useful indicator for predicting as close a set of correlation curves of light intercepted as could be desired for
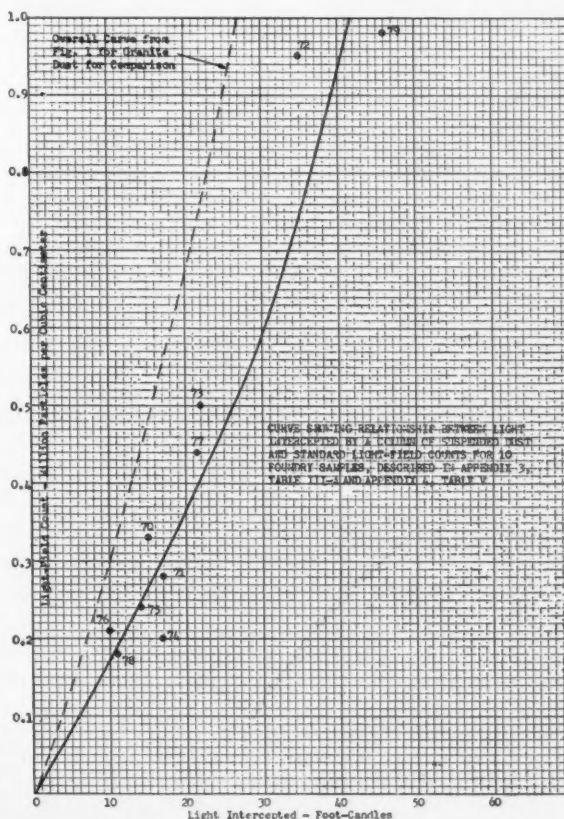

Fig. 2.

TABLE V.

COMPARISONS OF SAMPLES AT FOUNDRIES FOR COUNTS ESTIMATED FROM LIGHT-INTERCEPTED VS. LIGHT-FIELD COUNTS

Sample No.	Million Particles Per Cubic Foot	
	Counts Estimated from Curve of Light Inter-cepted vs. Light-field Count	Standard Light-field Count
70	3.39	4.13
71	1.80	1.65
72	4.69	5.93
73	1.72	2.09
74	7.52	4.94
75	0.97	0.94
76	1.35	1.67
77	4.27	4.69
78	0.77	0.73
79	27.8	23.1

use as bases of reference from which to derive counts on unknown samples to substitute freely for standard light-field counts, various brief experiments were made to try to account for the difficulties. One of these trials consisted of rough measurements of particle size-distribution for six samples, Nos. 48-53 inc., collected from sources described in Appendix 2 and numbered as plotted on Fig. 1, Appendix 2.

The measurements of the size-distribution were made rather rapidly with the hemacytometer cell by the method suggested by Williams.[3] On each sample counts were made of 200 particles estimated to fall within several ranges of size. The results are shown in Table VII, from which size-distribution curves are plotted in Fig. 4.

Our particle sizes in Fig. 4 appear larger than those in size-distribution studies reported by Bloomfield and DallaValle[1] but theirs included measurements of particles much below 0.9 microns. From the curves in Fig. 4 it will be noticed that Sample No. 50 is finer dust than the other five, these five being much alike. To Fig. 1, Appendix 2, has been added a curve to show the smooth

relationship of these five samples of larger size, and their consistent interception of more light than the average curve for all granite samples. Sample No. 50 corresponds closely to the average curve in this respect. The correlation of this sample with the other five for both the rough size-distribution measurements, and the curves of light intercepted vs. light-field count, indicates that rapid estimates of size-distribution may be worked out so that calibration curves for the various size grouping may be used to furnish close estimates of counts for unknown samples. This would obviate the necessity of using judgment when estimates are made for certain types of dust and sets of samples taken within a time-interval series as was required in the present study. This set of six was the only one upon which these size-distribution estimates were made, no discrepant results having been obtained in another series.

The indications from these and other studies are that the size-distribution curves are much of a pattern in the usual run of field samples so that it may prove possible to use the mean size for the purpose just discussed with few, if any, supporting measurements for distribution. This suggests the desirability of attempting to establish correlations with the mean sizes obtained by tyndallometer readings as described by Hatch and Choate[6] in the hope that the count and size may be obtained from two rapid readings (or perhaps slightly more than two, if effects of varying dusts on light should require it.)

Another experiment was made to attempt to explain divergences of light intercepted from the average curve by fractionating a special sample of a heavy concentration of granite dust (267 m.p.p.c.f.) which had been diluted from 75 to 500 cc. This was settl d overnight and 150 cc. of the supernatant liquid taken for counts and measurements of light intercepted. For comparison, the 350 cc. of sediment was diluted to give the same measurement of light intercepted as the supernatant liquid, and counts were made. Ten, 20, 30, etc., to 100% dilutions of each portion were read for light intercepted and plot-
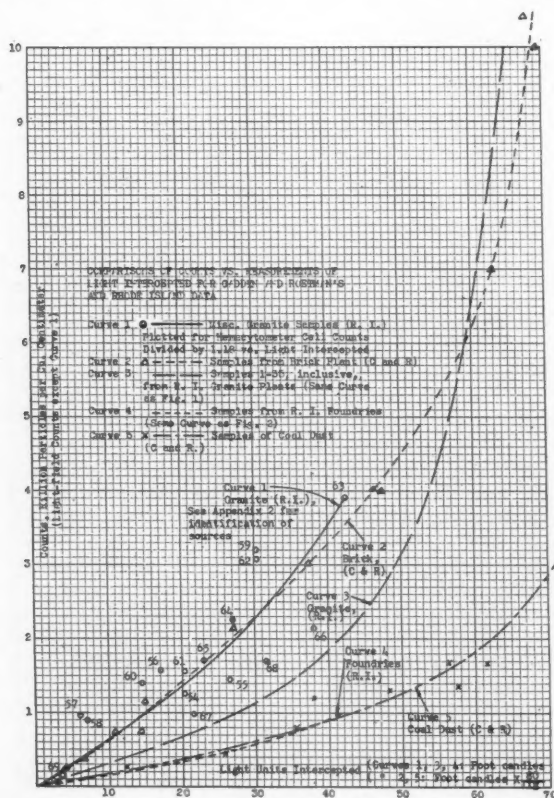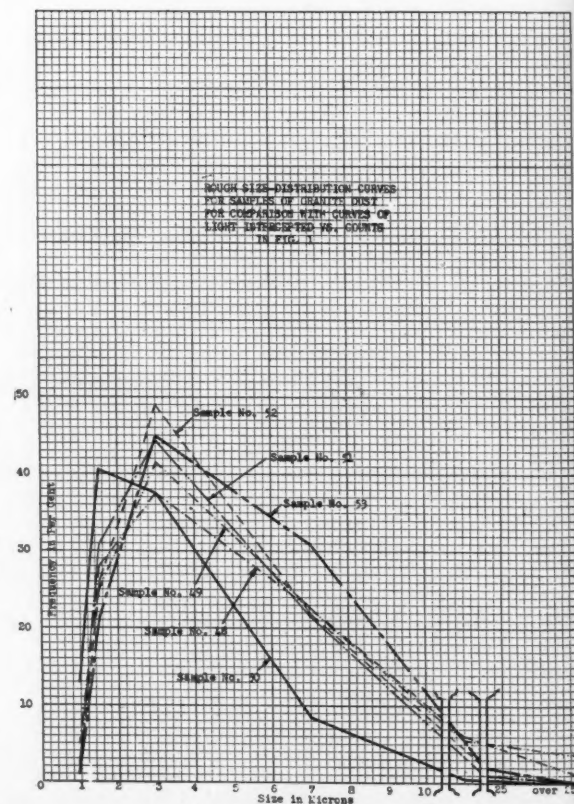

Fig. 3.

Fig. 4.

TABLE VI.

MEASUREMENTS OF LIGHT INTERCEPTED AND COUNTS FROM GRAB SAMPLERS COMPARED WITH LIGHT-FIELD COUNTS

Method of Determination; Source	No. of Samples	Range of Dust Concentrations by Standard Light-field Count, M. P. Per C. F.	Ratio of Instrument Determination to Standard L. F. Count			Mean Error for Determination vs. Standard L. F. Count, %	Refs.
			Minimum	Maximum	Median		
Light Intercepted, R. I. Granite							
Samples 1–35, inc............	35	0.6 –466.	0.61	3.20	1.05	±27	
Samples 40–53, inc...........	14	4.1 –128.5	0.35	1.59	0.94	±37	
Light Intercepted, R. I. Foundries							
Samples 70–79 inc............	10	0.73– 23.1	0.79	1.52	0.97	±17	
Kotze Konimeter							
Grinding Shop...............	6	1.3 – 21.7	0.68	3.98	1.66	(±103*)±46	17
Hollow Silverware Sand Buffing	22	1.8 – 6.9	0.30	3.30	1.30	(± 59*)±34	17
Hollow Silverware, Machine Buffing..................	12	0.5 – 4.5	0.70	2.50	1.15	(± 45*)±36	17
Tripoli Buffing..............	12	1.2 – 3.0	1.10	2.90	2.05	(±104*)±21	17
Owens-Hatch							
Granite dust................	11	2.7 – 45.0	0.53	1.28	0.86	(± 18*)±17	18
Foundry dust...............	7	45–246.	0.96	1.35	1.12	(± 13*)± 9	18
Bausch & Lomb							
Granite (0.1 mm. slot)........	4	19.3 –178.	0.26	0.63	0.32	(— 62*)±34	19
Granite (0.4 mm. slot)........	4	19.3 –178.	0.32	0.77	0.51	(— 47*)±30	19
Iron Foundry (0.1 mm. slot)....	4	3.2 – 47.5	0.92	2.44	1.26	(± 52*)±35	19
Iron Foundry (0.4 mm. slot)....	6	3.2 – 47.5	0.52	1.06	0.61	(± 32*)±26	19
Brass Foundry (0.1 mm. slot)...	3	2.8 – 30.4	3.15	9.50	4.45	(±470*)±45	19
Brass Foundry (0.4 mm. slot)...	4	2.8 – 30.4	1.16	8.55	3.56	(±320*)±51	19
Zeiss Konimeter							
Drilling rock................	8	2.7 – 21.4	0.74	1.85	0.93+	(± 34*)±35	20
Mucking....................	9	2.4 – 29.2	0.53+	1.90	1.07	(± 31*)±25	20

*Values unadjusted to take into account the fact that the instrument may not be expected to check the standard L. F. count for a given type of dust, but rather to check a constant factor of the standard. The adjusted figures given beside each value in parentheses were obtained by dividing the instrument determinations by the mean ratio of these determinations to the light-field counts for each set, and then calculating the mean error. These final values give a fairer comparison with the values for the light intercepted. The significance of the minimum and maximum ratios as indicators of extremes in departures for these comparisons lies in their variation from the median ratio for each set rather than in their variation from unity.

ted against counts in Fig. 5. It was thought that the shapes of the curves, including the curves, for the dilutions might vary because of several factors, and if the variation was sufficient, these might be used to relate subsequent unknown samples to special curves for counts obtained from measurements of light intercepted, instead of relating them to the average curve, so as to get closer coordination with standard counts.

The special sample as shown in Fig. 5 indicates that these dilution curves do vary with change in size and uniformity of the dust and vary enough to distinguish amongst samples in practice. The supernatant and sedimented portions represent roughly the extremes of sizes that would be encountered, as judged from the dark-field vs. light-field ratios. The different shapes taken by these curves are presumed to be due largely to changing amounts of obstruction to light of one particle behind another with the different dilutions, and probably a change in reflection of light by different sizes. Two additional samples on which dilutions were made without fractionating are plotted in Fig. 5 for comparison. The curves vary enough in shape to suggest that the differences may be made use of. This method of dilution is rapid and may have possibilities for eliminating the judgment required to distinguish what types of dust are to be related to which curves when these vary from the overall average curve for granite dusts in general.

The only other trial of pertinent significance here was a series of counts and measurements of light intercepted made on fractions of samples separated by varying periods of sedimentation, and of centrifuging. The purpose of this series was to determine whether a more uniform fraction of a sample could be obtained by elimination of particles of extreme sizes to make it correlate better for light intercepted vs. count, and then by establishing a correlation between the prepared fractions and the original sample, give the desired results. Not enough work was done on this series to evaluate the effect of the extreme sizes on the measurements of light intercepted or to indicate a probable fruitful approach to the improved correlations desired, but the impression was gained that the particles of extremes in size probably will not nullify

TABLE VII.

SIZE-DISTRIBUTION OF SIX SAMPLES OF GRANITE DUST

Sample No.	Per Cent of Particles Falling Within Size Ranges in Microns					
	Below ½	1 to 2	2 to 4	4 to 10	10 to 25	Over 25
48	5	28	37.5	22.5	6	1
49	2	25	41.5	22.5	5.5	3.5
50	13	40.5	37.5	8.5	0.5	0
51	2	31	44.5	21.5	1	
52	1	26	49	22	2	
53	1	21	45	31	2	

the obtaining of the objectives by the first method described in this appendix.

It may be well to note here an approach pointed out by Camp[21] which is being used in studies in soil mechaincs by Gilboy and Taylor[22] and in ceramics by Norton and Speil[23,24] whereby suspensions of nearly monodispersed systems of sizes within the ranges of interest to us for evaluating their several effects on light intercepted can be prepared. These references in turn refer to other references on various approaches to the problem.

References:

1. BLOOMFIELD, J. J., and DALLAVALLE, J. M.: The Determination and Control of Industrial Dust, Pub. Health Bull. No. 217, Washington, 1935 (or 1938 Reprint).

2. WILLIAMS, C. R.: A Method of Counting Samples Taken With the Impinger, *J. Indust. Hyg. & Tox.*, Vol. 21, No. 6, June, 1939.

3. Report of Sub-committee on Dust Procedures in Air Analysis, Amer. Pub. Health Assn. Year Book, 1940-41.

4. HATCH, T., and POOL, C. L.: The Quantitation of Impinger Dust Samples by Dark-field Microscopy, *J. Indust. Hyg. & Tox.*, Vol. 16, No. 3, May, 1934.

5. CADDEN, J. F., and ROETMAN, E. T.: A Photometric Method for Making Dust Determinations, Bull. of State Dept. of Health, Charleston, W. Va., Feb., 1939.
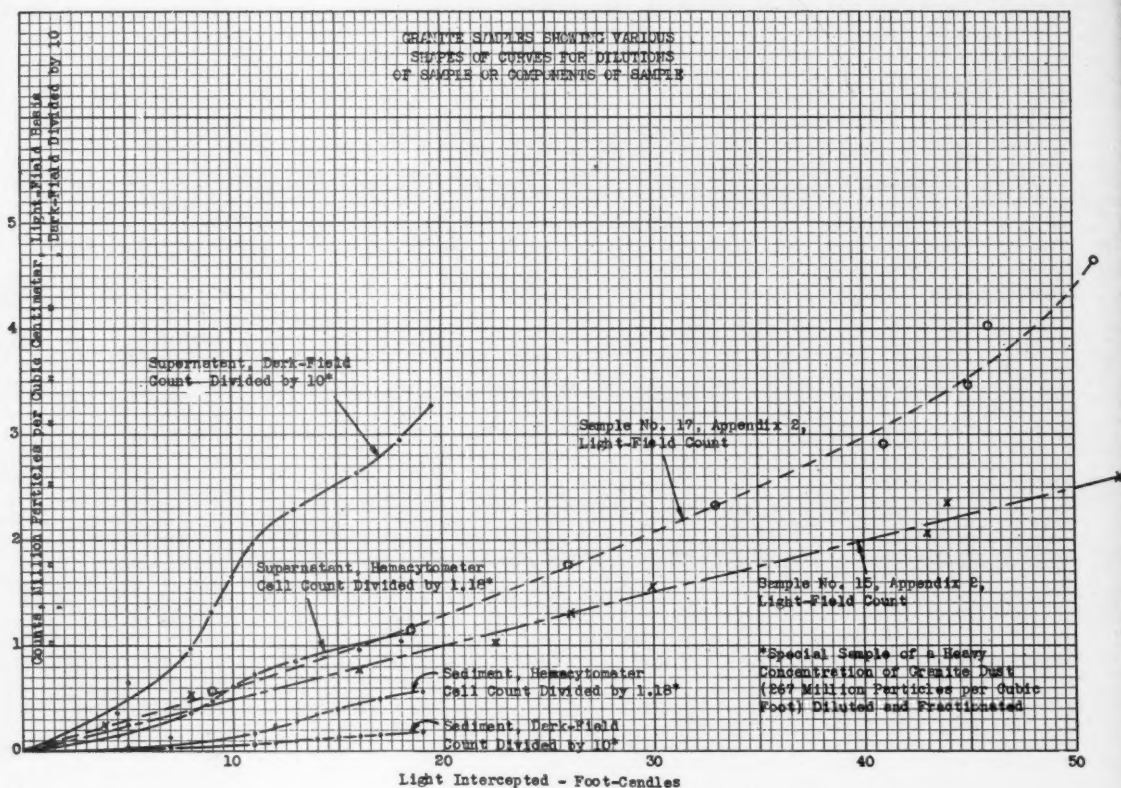
GRANITE SAMPLES SHOWING VARIOUS
SHAPES OF CURVES FOR DILUTIONS
OF SAMPLE OR COMPONENTS OF SAMPLE

Supernatant, Dark-Field
Count Divided by 10*

Sample No. 17, Appendix 2,
Light-Field Count

Supernatant, Hemacytometer
Cell Count Divided by 1.18*

Sample No. 15, Appendix 2,
Light-Field Count

Sediment, Hemacytometer
Cell Count Divided by 1.18*

*Special Sample of a Heavy
Concentration of Granite Dust
(267 Million Particles per Cubic
Foot) Diluted and Fractionated

Sediment, Dark-Field
Count Divided by 10*

Light Intercepted - Foot-Candles

Fig. 5.

6. ROETMAN, E. T.: Indust. Hygiene Engr., State Dept. of Health, Charleston, W. Va.: Personal Communication.

7. BARNES, E. C., Indust. Engr., Med. Dept., Westinghouse Elec. & Mfg. Co., Pittsburgh: Personal Communication.

8. HATCH, T., and CHOATE, S. P.: Measurement of Polarization of the Tyndall Beam of Aqueous Suspensions as an Aid in Determining Particle Size, *J. Franklin Institute*, Vol. 210, No. 6, Dec., 1930.

9. STRATTON, R. C.: Supervising Chem. Engr., Eng. and Insp. Divis., Travelers Insurance Co., Hartford: Personal Communication.

10. BROWN, C. E.: Chemist, Gas and Dust Sec'n., U. S. Bur. of Mines Expt. Sta., Pittsburgh: Personal Communication.

11. HATCH, T., Assoc. Prof. of Indust. Hygiene, Sch. of Med., Univ. of Pennsylvania, Philadelphia: Personal Communication.

12. HAZARD, W. G., Personnel Div., Owens-Illinois Glass Co., Toledo, O.: Personal Communication.

13. DRINKER, P., Prof. of Indust. Hygiene, Harvard School of Public Health, Boston: Personal Communication.

14. WILLIAMS, C. R., Liberty Mutual Insurance Co., Boston: Personal Communication.

15. ROTHMANN, S., Indust. Hygiene Engr., State Compensation Commission, Charleston, W. Va.: Personal Communication.

16. BLOOMFIELD, J. J., Chief, States' Relations Sec'n., Divis. of Indust. Hygiene, Nat'l Institute of Health, Bethseda, Md.: Personal Communication.

17. GREENBURG, L., Studies on the Industrial Dust Problem, III. Comparative Field Studies of the Palmer Apparatus, the Konimeter, and the Impinger Methods for Sampling Aerial Dust, Pub. Health Reports, Vol. 40, No. 31, Washington, July 31, 1925.

18. HATCH, T., and THOMPSON, E. W.: A Rapid Method of Dust Sampling and Approximate Quantitation for Routine Plant Operation, *J. Indust. Hyg.*, Vol. 16, No. 2, Mar., 1934.

19. GURNEY, S. W., WILLIAMS, C. R., and MEIGS, R. R.: Investigation of the Characteristics of the Bausch and Lomb Dust Counter, *J. Indust. Hyg. & Tox.*, Vol. 20, No. 1, Jan., 1938.

20. COLEMAN, A. L., Chf. Indust. Hygienist, State Dept. of Health, Hartford, Conn.: Personal Communication.

21. CAMP, T. R., Prof. of Sanitary Eng., Mass. Institute of Technology, Cambridge, Mass.: Personal Communication.

22. GILBOY and TAYLOR, Dept. of Civil and Sanitary Eng., Mass. Institute of Technology, Cambridge, Mass., Extracts from "Notes on Soil Mechanics": Personal Communication.

23. NORTON, F. H., and SPEIL, S.: The Measurement of Particle Size in Clays, *J. Amer. Ceramic Soc.*, Vol. 21, No. 3, Mar., 1938.

24. NORTON, F. H., and SPEIL, S.: The Fractionation of a Clay Into Closely Monodispersed Systems, *J. Amer. Ceramic Soc.*, Vol. 21, No. 10, Oct., 1938.

St. Louis Section

A ST. LOUIS Section of the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION has been organized to promote industrial health work in the area. Officers for the first year are: Chairman: H. A. THIEMANN, engineer, Hartford Accident & Indemnity Co.; Vice-Chairman: JOHN BUXELL, chief engineer, Industrial Hygiene Service, St. Louis Health Division; Secretary-Treasurer, AGNES RABITT, nurse, Anheuser-Busch Co.

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